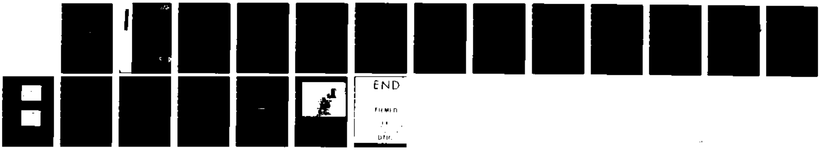
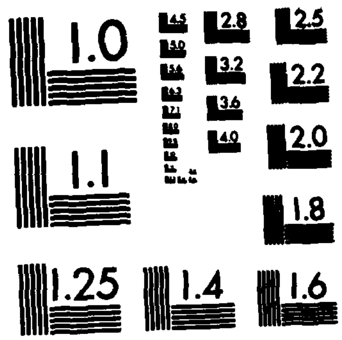
AD-A126 222 MICROWAVE CONDITIONED DC DISCHARGES FOR EXCITATION OF RARE-GAS-HALIDE LASERS(U) MISSION RESEARCH CORP ALEXANDRIA VA W M BOLLEN ET AL. DEC 82 MRC/WDC-R-048 N00014-82-C-2257 1/1

UNCLASSIFIED F/G 20/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A 126222

12

MRC/WDC-R-048

TECHNICAL REPORT

MICROWAVE CONDITIONED DC DISCHARGES FOR EXCITATION OF RARE-GAS-HALIDE LASERS

W. M. Bollen
Mission Research Corporation

C. P. Christensen
Potomac Photonics Corporation

R. W. Waynant
R. L. Burnham
Code 6540
Naval Research Laboratory

December 1982

Prepared for: Naval Research Laboratory
4555 Overlook Avenue, S. W.
Washington, DC 20375
Attn: Code 6540

Contract No: N00014-82-C-2257

MISSION RESEARCH CORPORATION
5503 Cherokee Avenue, Suite 201
Alexandria, Virginia 22312
(703) 750-3556

Copy : 19

MRC/WDC-R-048

TECHNICAL REPORT

MICROWAVE CONDITIONED DC DISCHARGES FOR EXCITATION OF RARE-GAS-HALIDE LASERS

W. M. Bollen
Mission Research Corporation

C. P. Christensen
Potomac Photonics Corporation

R. W. Waynant
R. L. Burnham
Code 6540
Naval Research Laboratory

December 1982

Prepared for: Naval Research Laboratory
4555 Overlook Avenue, S. W.
Washington, DC 20375
Attn: Code 6540

Contract No: N00014-82-C-2257

MISSION RESEARCH CORPORATION
5503 Cherokee Avenue, Suite 201
Alexandria, Virginia 22312
(703) 750-3556

CONTENTS

1.0 INTRODUCTION

Discharge-pumped rare-gas halide (RGH) lasers have undergone extensive development during the last five years. Applications of these lasers in systems requiring pulse energies of several joules and repetition rates of up to one kilohertz are now under consideration. Yet there remain several unsolved problems with discharge-pumped RGH lasers which limit their applicability in systems requiring long operating lifetimes. The switch used to control the current applied to the discharge is one of these problems. Other problem areas include impurities, which can reduce the performance of RGH lasers, and stable operation, which requires a good preionization scheme. A number of approaches to solve these problems are under investigation. In the following report we outline in more detail the nature of these problems. We discuss possible solutions based on microwave excited discharge technology and actual experiments that have been performed applying these methods.

The application of microwave techniques to RGH laser technology is particularly appealing because of the advanced state of microwave devices. High-power (multiple megawatt) sources in the 1-10 GHz range with microsecond pulse lengths and kilohertz repetition rates are available. Experimental devices have demonstrated gigawatt power levels. Transport of these high-power levels can be accomplished using standard techniques.

2.0 LIMITATIONS ON DISCHARGE-PUMPED EXCIMER LASER TECHNOLOGY

During the course of development of discharge-pumped excimer lasers, several problems have become apparent which tend to reduce the reliability and efficiency of these devices to levels which are only marginally acceptable. These problems are generally associated with the nature of the RGH laser discharge. Their solution would provide great impetus for the incorporation of RGH lasers into economically viable applications.

First, the requirement for several joules of laser output in a pulse length of 50 to 100 nanoseconds necessitates an electrical pump pulse power of 1-2 GW. This electrical pulse must be delivered with a risetime of 10 to 20% of the total pulse length in order to obtain efficient optical extraction. This pulsed power requirement may be combined with the known voltage and pressures at which RGH laser discharges operate (1 kV/cm-Atm, 3-5 Atm) to determine the peak discharge current requirement:

$$I = P/V \simeq 10^9 / (2 \times 10^4) = 5 \times 10^4 \text{ A}. \tag{1}$$

Since this current must turn on in approximately 10^{-8} seconds the current risetime requirement is

$$\tau_R \simeq 5 \times 10^{12} \text{ A/sec}. \tag{2}$$

This current risetime requirement places the most stress on components in the pulsed power sources for RGH lasers. In particular, the high dI/dt excludes the use of thyratron switches which have operating lifetimes of approximately 10^4 hours at current risetimes of less than 5×10^{11} A/sec. The only switch which has been identified as capable of meeting this current risetime requirement is the multichannel railgap. This switch has sufficiently low inductance for application in RGH lasers. However, electrode erosion presently limits the railgap to lifetimes of 10^7 to 10^8 shots. This is a short lifetime, and it is extremely desirable to find an alternative to the high-current-risetime switching techniques presently in use for RGH lasers.

A second requirement for efficient excitation of discharge-pumped RGH lasers relates to the magnitude and uniformity of the preionization from which the laser discharge develops. Levatter and Lin[1] have recently shown that if a certain minimum preionization is supplied, then uniform, stable discharges can be maintained in RGH gas mixtures for

up to 200 nsec. The required initial preionizing electron density is approximately 10^6 cm^{-3}. This is presently supplied by either UV spark sources or x-ray preionization. However, for long-lived laser systems UV spark preionizers are subject to erosion which limits their lifetimes and also contaminates the laser-gas mixtures. X-ray preionizers are chemically clean, since the source is separated from the active laser medium; however, x-rays have poor deposition into the laser-gas mixture. This results in an extremely uniform initial electron distribution, since the range of x-rays in the laser gas can be up to several meters, but limits the electron density that the preionizer can generate.

The limited preionization density that can be produced by x-ray preionization is the most serious limitation on this technique. In initial experiments with x-ray preionization, Levatter and Lin and others used modified electron beam machines as x-ray sources. These devices have current densities as large as 10 A/cm^2 and operating voltages between 200 to 500 keV. Both the current density and operating voltages must be scaled down significantly in x-ray generators to be used with high repetition-rate lasers. In scaling down the voltage and current, the initial preionization which can be produced in RGH laser gas mixtures is also reduced. For example, an x-ray generator running at approximately 0.1 A/cm^2 and 50-100 keV will provide a source strength in the laser gas of 10^{13} - 10^{14} $e\text{-}cm^{-3}$ sec^{-1}. The attachment rate for electrons in the gas mixture will be about 10^7 sec^{-1}; therefore the steady state electron density produced in the gas by the x-rays will be on the order of 10^6 - 10^7 cm^{-3}. This electron density exceeds the criterion set down for minimum preionization levels[1], and such an x-ray source appears to be at least sufficient for use in RGH lasers. However, while x-ray preionization can supply adequate electron densities for preionization, recent numerical calculations at NRL and elsewhere indicate that significant improvement in the efficiency of discharge-pumped RGH lasers can be expected if the preionization density can be increased by several orders of magnitude over the minimum required level. The improvement

arises primarily due to reduced formation times for RGH discharges at the increased preionization levels. During the discharge formation period the low-impedance pulsed power supply is very poorly matched to the laser discharge and most of the electrical energy delivered to the discharge during this interval is reflected back into the pulse-forming network and subsequently lost. The discharge formation period is the time required for the electron density to avalanche from the preionization level of approximately 10^{15} cm^{-3}, to the level at which the discharge operates. For preionization densities of 10^6 - 10^7 cm^{-3}, this formation time is on the order of 20 nsec. Thus, for a 50 nsec electrical pump pulse, 40% of the stored electrical energy can be wasted. If, on the other hand, electrons avalanche from an initial preionization density of 10^{10} - 10^{12} cm^{-3} (a level believed possible using microwaves), then the discharge formation time can be reduced to 10 nsec. For this condition the discharge formation time closely matches the switch closure time and very little of the stored electrical energy is lost. Thus, improvements in laser efficiency of between 20 and 40 percent may be possible with increased preionization.

We have summarized the problems which limit the operating lifetime and efficiency of discharge-pumped excimer lasers. The most serious of these problems is the requirement for a very fast high-current closing switch. In addition, calculations indicate that significant improvements could be made in overall laser efficiency by employing more intense preionization than can be obtained from the x-ray sources currently under consideration.

In the following section, results of experiments performed utilizing high-power microwave sources for laser-discharge switching and preionization are discussed. This approach has the advantage of utilizing the highly reliable, efficient, available microwave technology.

3.0 MICROWAVE INVESTIGATIONS ON PREIONIZATION AND SWITCHING

3.1 Microwave Conditioning

Microwave generation of a plasma discharge for RGH laser preionization is extremely desirable. Unlike UV preionization, this is a clean method which does not introduce impurities. Large preionization densities, which are believed to be required for high efficiency operation, are possible. The limit on density occurs when the plasma reflects the microwaves. Total reflection occurs at the critical density, $N_c = 3.15 \times 10^{-10}(\omega^2 + \nu^2)$, where ω is the natural frequency of the microwaves and ν is the electron-neutral collision frequency. The critical density can be quite large because ν can be quite large at the high pressure at which the laser operates. For example, at a 1 atmosphere pressure of helium ν will be approximately 10^{12} sec^{-1}, and for 10 GHz microwaves we calculate N_c to be 3×10^{14} cm^{-3}. The deposition of microwave energy will be large until the density reaches critical. For example, 80% absorption for microwave excitation of nitrogen discharges has been observed[2]. In addition to clean, high-density discharges, microwaves are capable of fast turn-on, thereby allowing for fast preionization. Work we have performed at NRL has resulted in 10 nsec risetimes for a 1 μsec microwave pulse (see Figure 1).

Microwaves may be used also to turn on the laser discharge. The main discharge switch is removed and the electrodes charged to a voltage below dc breakdown. Microwaves are then used to ionize the laser gas mixture allowing the discharge to form and break down across the electrodes. Since fast risetime microwave sources are available, this technique can effectively act as a fast switch for the laser discharge, thus meeting the requirements of equation 2. Long lifetimes can be expected.

3.2 Experimental Invesitgations

Three preliminary experimental geometries have been used to evaluate microwave preionization and switching: 1) end-feed, 2) waveguide, and 3) side-feed. These experiments are discussed below. This work suggests that microwaves do indeed hold promise, but more research must be performed before a definitive statement can be made.

3.2.1 End-Feed Experiment

The first experiment performed to evaluate microwave preionization and switching used a standard dc discharge RGH laser (see Figure 2). One of the windows was modified to allow microwaves to be introduced from a waveguide. This worked effectively as a preionizer and was also able to switch the external power under certain restrictive conditions. A laser could not be demonstrated. A small mirror was glued across the microwave inlet and alignment was difficult. The mirror was small enough not to significantly interfere with the microwaves. The microwaves tended to flash over the window between the laser mixture and the waveguide. This reduced the microwave energy into the laser mixture. Also, the open waveguide did not effectively concentrate the microwaves between the electrodes.

As a result of this experiment, it was decided a better method of injecting the microwaves between the electrodes was required. An experiment designed to do this is described in the following subsection.

3.2.2 Waveguide Geometry

The main problem in the previous experiment was believed to be poor injection of the microwaves into the region between the discharge electrodes. This resulted in most of the preionization occurring in regions of the laser not between the electrodes. In order to solve this

problem a new laser discharge chamber was designed (see Figure 3). A ridge waveguide design was employed to concentrate the microwaves between the electrodes (see Figure 4). A dielectric was used to electrically isolate the lower electrode from the upper electrode. Unfortunately, this design made large use of plastics and elastimers for dielectrics to perform the isolation and outgassing was a significant problem. The impurities introduced by the outgassing degraded the operation of the laser. A side window was included in the chamber to allow observation of the discharge. The microwaves were seen effectively to ionize the gas mixture between the electrodes. The microwave penetration along the electrodes was limited by absorption and reflection to a few centimeters and only this region carried the discharge current. The discharge itself was not as uniform as hoped for. This was contributed to poor electrode shape and the large amount of impurities present. The results were encouraging because of the ability to easily switch on the discharge. Laser mixtures were easily switched at pressures used in RGH lasers. With the information gained in this experiment, an improved geometry was designed.

3.2.3 Side-Feed Geometry

Many of the difficulties (impurities, electrode design) in the previous experiment were attributed to poor discharge laser design. The waveguide geometry had been designed to optimize the microwave interaction and not necessarily the laser operation. For this reason, a return to a standard dc discharge-laser design was decided upon. Microwaves were introduced through the side after expansion in a horn (see Figure 5). The experimental device is shown in Figure 6. The expansion was performed to reduce the intensity at the window and thus try to prevent flashover. Further, the horn directed the output microwaves between the electrodes. This design still suffered from the fact that microwave intensity was highest at the window. The side-feed also allowed the microwaves to penetrate the full depth across the electrodes rather than forcing them to

penetrate the length, which they could not do. Good microwave penetration was observed. Good preionization was observed and laser operation was observed. Upon close examination, the dominant preionization resulted from UV emission of the plasma formed by flashover of the window. Switching by the microwaves was unable to be accomplished in this experiment.

An upgrade to this experiment was performed by using a dielectric waveguide. A dielectric was placed inside the horn and terminated just before the electrodes. This concentrated the microwaves inside the dielectric and allowed microwave injection immediately at the electrodes. This improved performance and allowed switching. However, the dominant ionizer is believed to be UV created in flashover of the dielectric. More work with this geometry is needed.

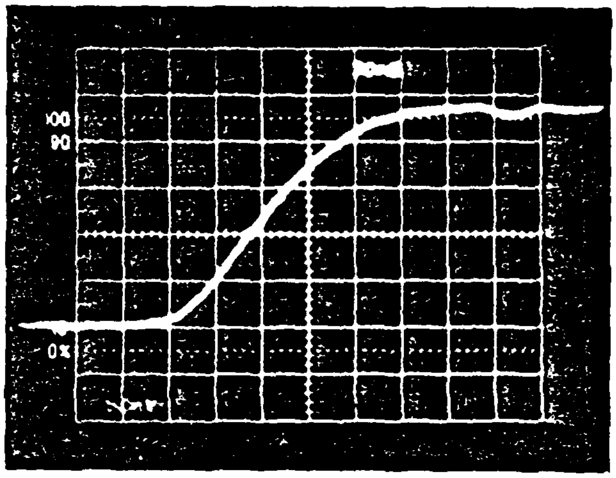
4.0 CONCLUSIONS

The results of these preliminary experiments are not definitive. The results are promising. Significant preionization using microwaves is possible. Some ability to switch the discharge and operate a laser have been demonstrated. More work needs to be performed to perfect the microwave coupling to the laser mixture. In particular, experiments with the microwaves better concentrated between the electrodes should be performed. The best way to accomplish this appears to be using the side-feed geometry; however, a larger expansion of the microwaves should occur (to well below the power able to break down the window), and then a cylindrical lense should be used to focus the microwaves between the electrodes.

REFERENCES

1. J. Levatter and S. L. Lin, J. Appl. Phys. 51, 210, (1980).

2. W. M. Bollen, C. L. Yee, and M. Nagurney, Mission Research Corporation Technical Report MRC/WDC-R-028, (1982).



20 ns/div.

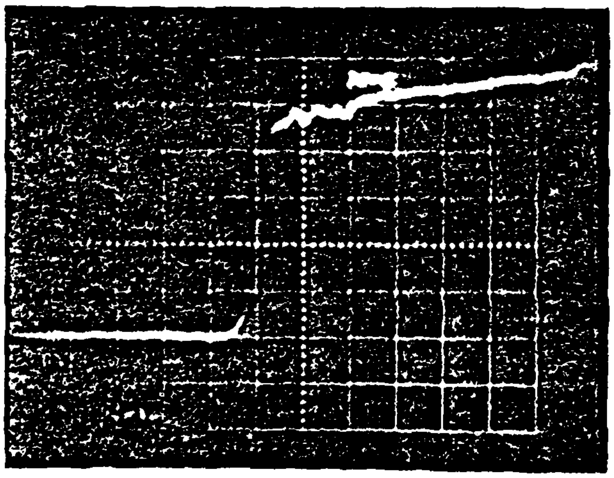


Figure 1

Microwave pulse, before and after pulse sharpening was performed, showing 10 ns risetime.

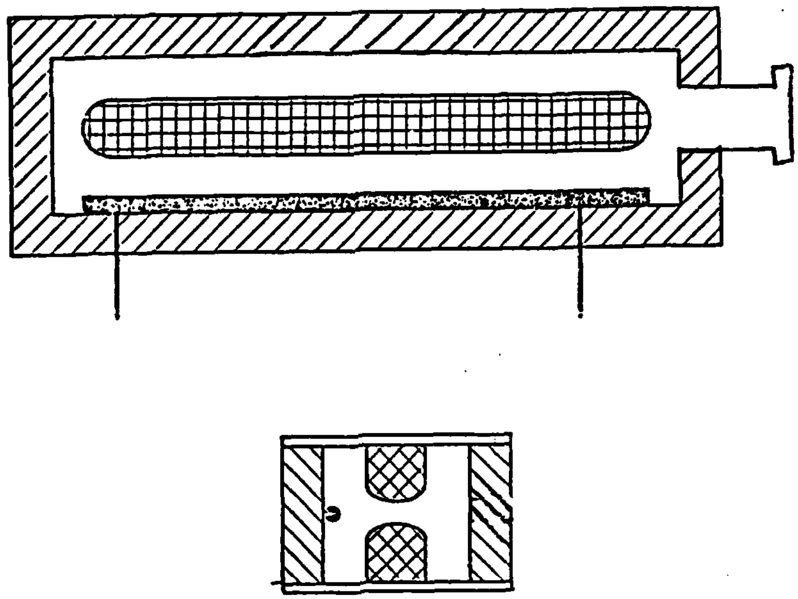


Figure 2

Schematic of the end-feed experiment. A standard dc discharge laser was used. The UV preionizer could be used as an option (dark cylinder).

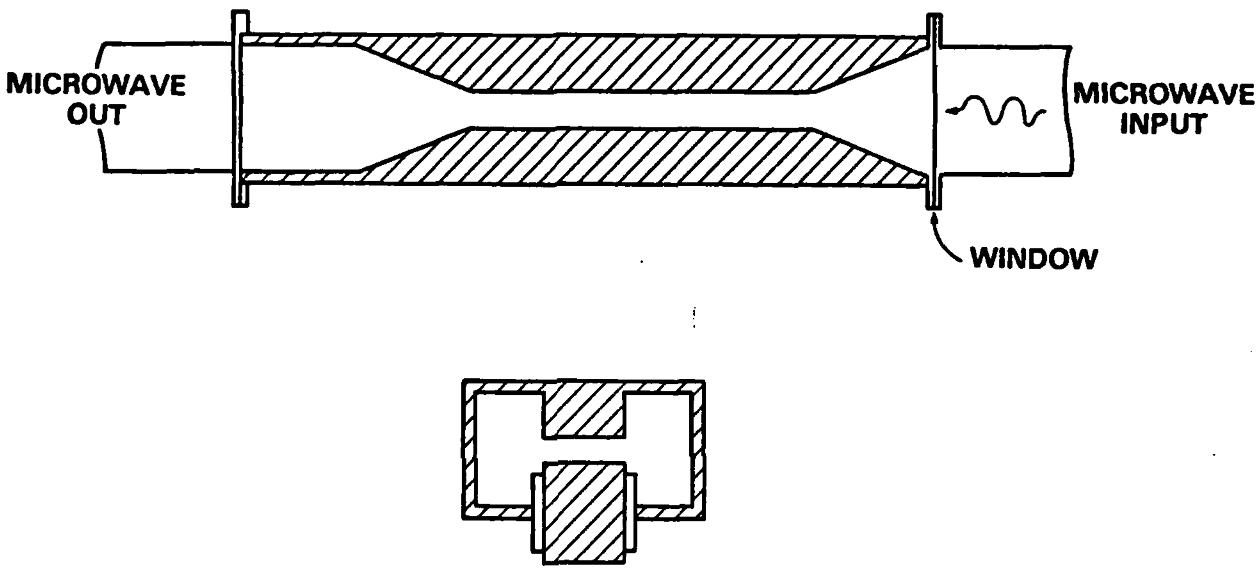


Figure 3

Schematic of waveguide experiment.

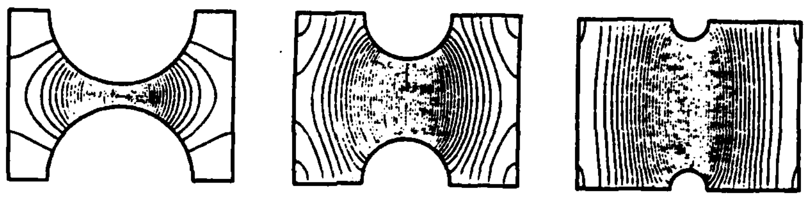


Figure 4

Electric field patterns for ridge waveguide. These patterns show the concentration of the electric field between the ridges.

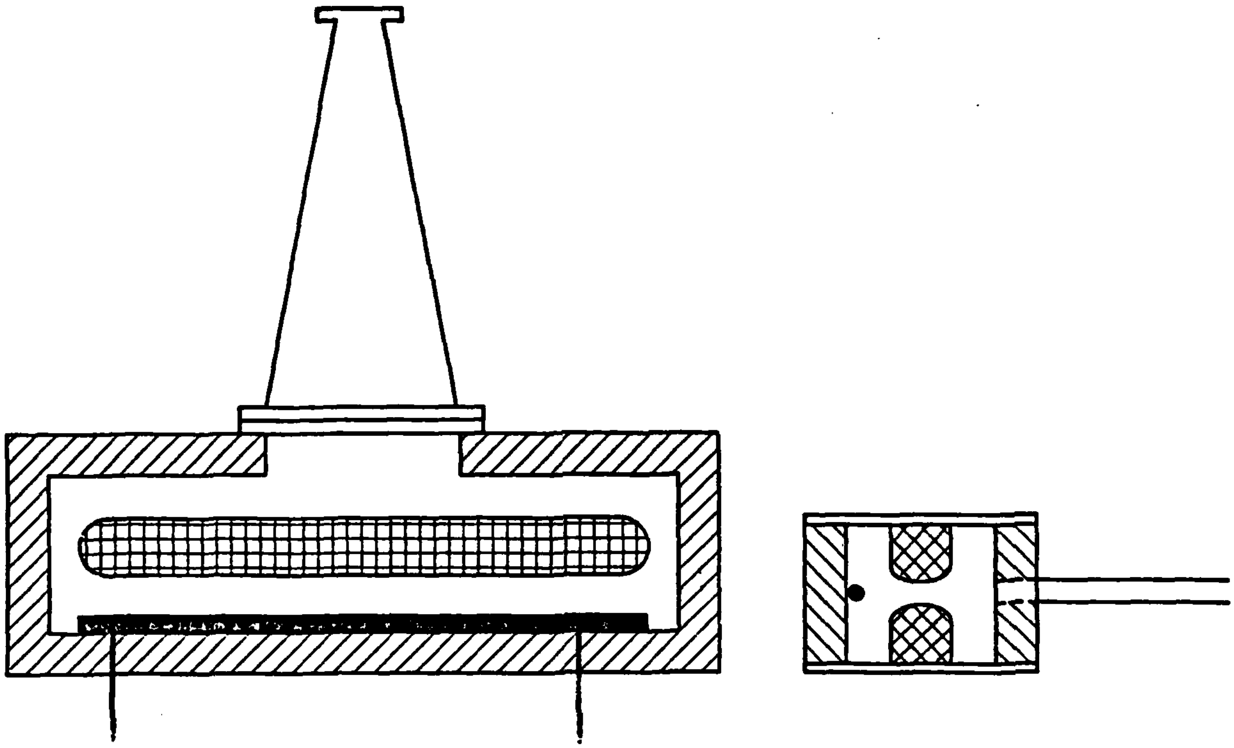


Figure 5

Schematic of side-feed experiment. This is a modified version of the chamber shown in Figure 2. Windows (not shown) were on either end of the chamber to allow lasing.

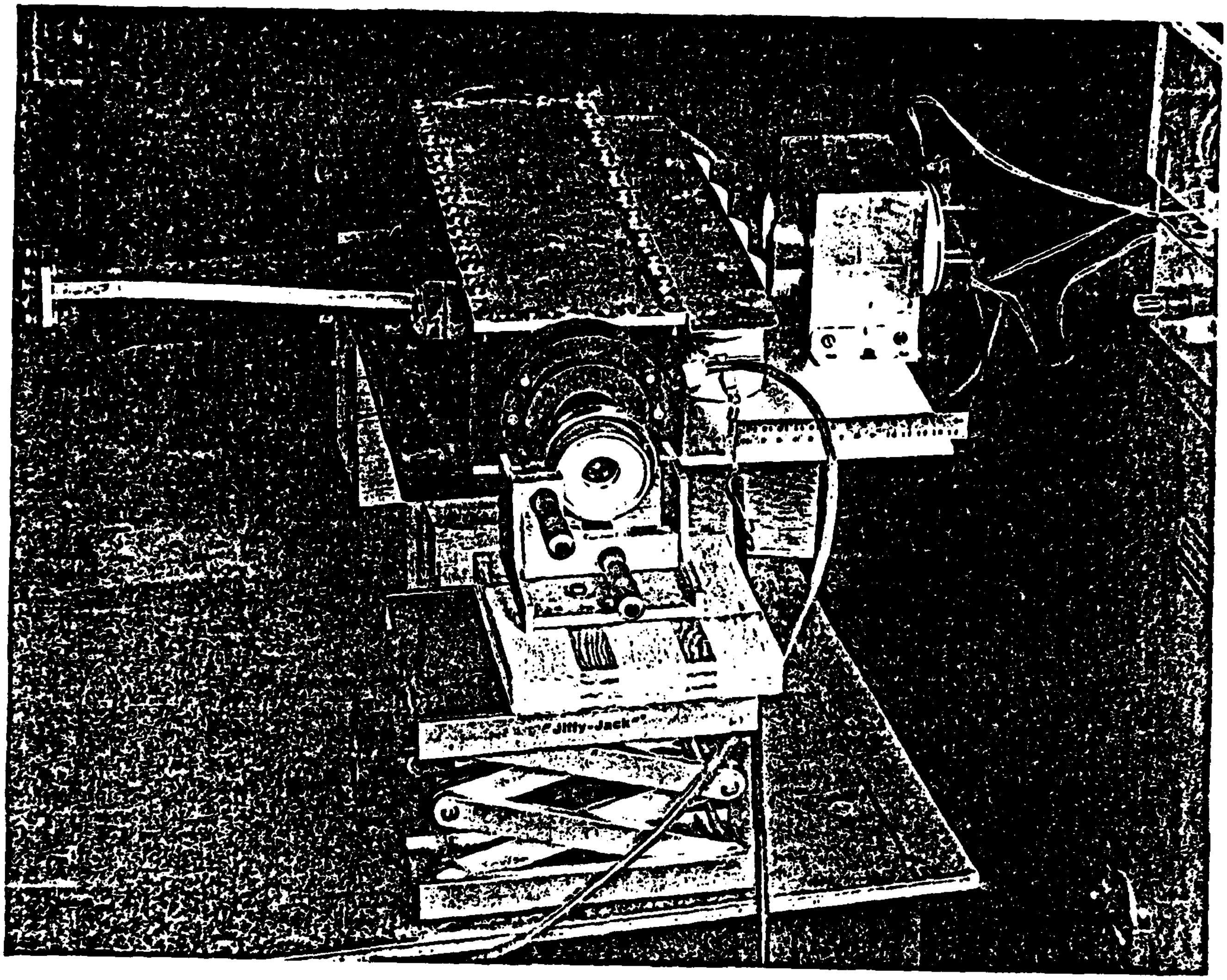


Figure 6

Photograph of side-feed experiment.